The Orocos User's Manual

Open RObot COntrol Software

1.2.2

The Orocos User's Manual : *Open RObot COntrol Software* : 1.2.2

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Abstract

This document gives an introduction to the Orocos [http://www.orocos.org] *(Open RObot COntrol Software)* project. It contains a high-level overview of what Orocos (aims to) offer and the installation manual.

Orocos Version 1.2.2.

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Chapter 1. Orocos Overview

This document gives an application oriented overview of Orocos [http://www.orocos.org], the *Open RObot COntrol Software* project.

1. What is Orocos?

"Orocos" is the acronym of the *Open Robot Control Software [http://www.orocos.org]* project. The project's aim is to develop a general-purpose, free software, and modular *framework* for *robot*and *machine control*. The Orocos project supports 4 C++ libraries: the Real-Time Toolkit, the Kinematics and Dynamics Library, the Bayesian Filtering Library and the Orocos Component Library.

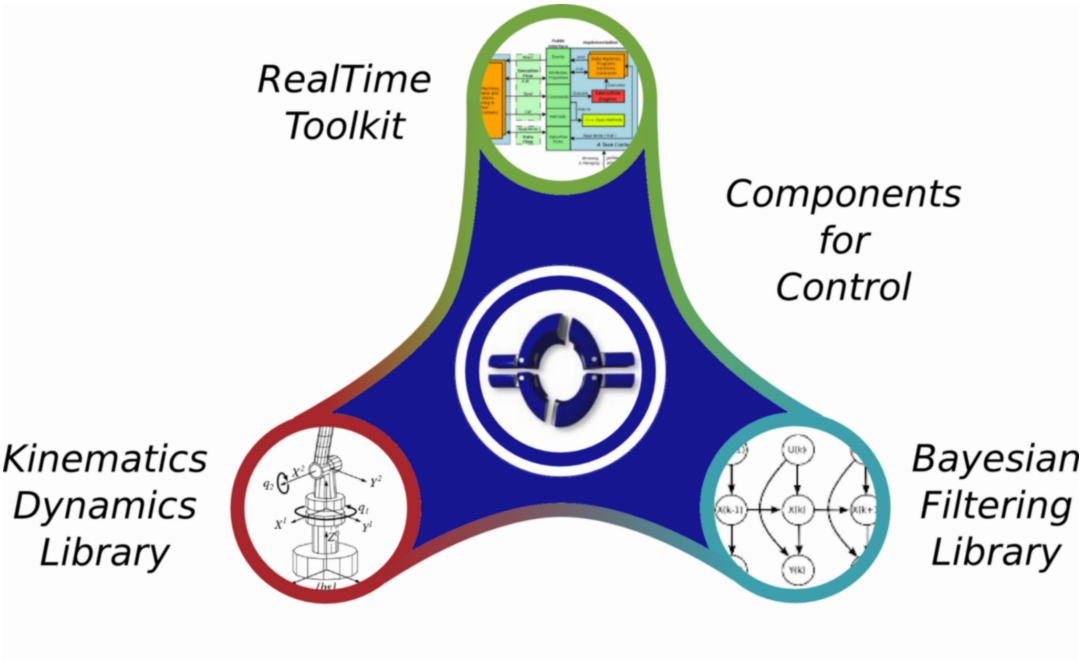


Figure 1.1. Orocos Libraries

- The Orocos Real-Time Toolkit (RTT) is not an application in itself, but it provides the infrastructure and the functionalities to build robotics applications in C++. The emphasis is on *real-time*, *on-line interactive* and *component based* applications.
- The Orocos Components Library (OCL) provides some ready to use control components. Both Component management and Components for control and hardware access are available.
- The Orocos Kinematics and Dynamics Library (KDL) is a C++ library which allows to calculate kinematic chains in real-time.

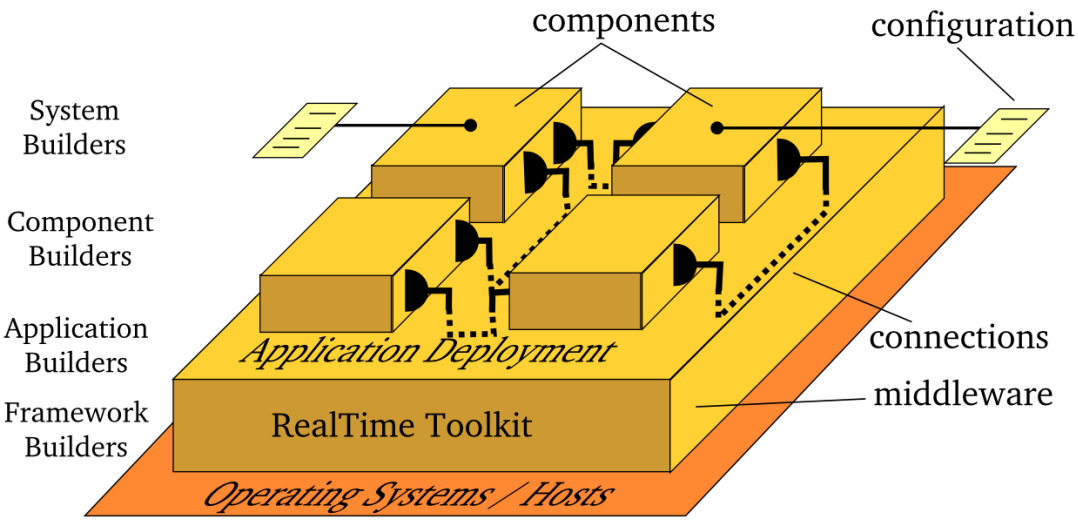
- The Orocos Bayesian Filtering Library (BFL) provides an application independent framework for inference in Dynamic Bayesian Networks, i.e., recursive information processing and estimation algorithms based on Bayes' rule, such as (Extended) Kalman Filters, Particle Filters (Sequential Monte methods), etc.

Orocos is a free software project, hence its code and documentation are released under Free Software licenses.

Your feedback and suggestions are greatly appreciated. Please, use the project's mailing list [http://lists.mech.kuleuven.be/mailman/listinfo/orocos] for this purpose.

2. Target audience

Robotics or machine control in general is a very broad field, and many roboticists are pursuing quite different goals, dealing with different levels of complexity, real-time control constraints, application areas, user interaction, etc. So, because the robotics community is not homogeneous, Orocos targets four different categories of "Users" (or, in the first place, "Developers"):



1. *Framework Builders.*

   These developers do not work on any specific application, but they provide the infrastructure code to support applications. This level of supporting code is most often neglected in robot software projects, because in the (rather limited) scope of each individual project, putting a lot of effort in a generic support platform is often considered to be "overkill", or even not taken into consideration at all. However, because of the large scope of the Orocos project, the supporting code (the "Framework") gets a lot of attention. The hope is, of course, that this work will pay of by facilitating the developments for the other "Builders". The RTT, KDL and BFL are created by Framework builders

2. *Component Builders.*

Components provide a “service” within an application. Using the infrastructure of the framework, a Component Builder describes the interface of a service and provides one or more implementations. For example a Kinematics Component may be designed as such that it can “serve” different kinematic architectures. Other examples are Components to hardware devices, Components for diagnostics, safety or simulation. The OCL is created by Component Builders.

3. *Application Builders.*

   These developers use the Orocos' Framework and Components, and integrate them into one particular application. That means that they create a specific, application-dependent *architecture*: Components are connected and configured as such that they form an application.

4. *End Users.*

   These people use the products of the Application Builders to program and run their particular tasks.

End Users do not directly belong to the target audience of the Orocos project, because Orocos concentrates on the common *framework*, independent of any application architecture. Serving the needs of the End Users is left to (commercial and non-commercial) Application Builders.

3. Building Orocos Applications

Orocos applications are composed of software components, which form an application specific network. When using Orocos, you can choose to use predefined components, contributed by the community, or build your own component, using the Orocos Real-Time Toolkit. This section introduces both ways of building applications.

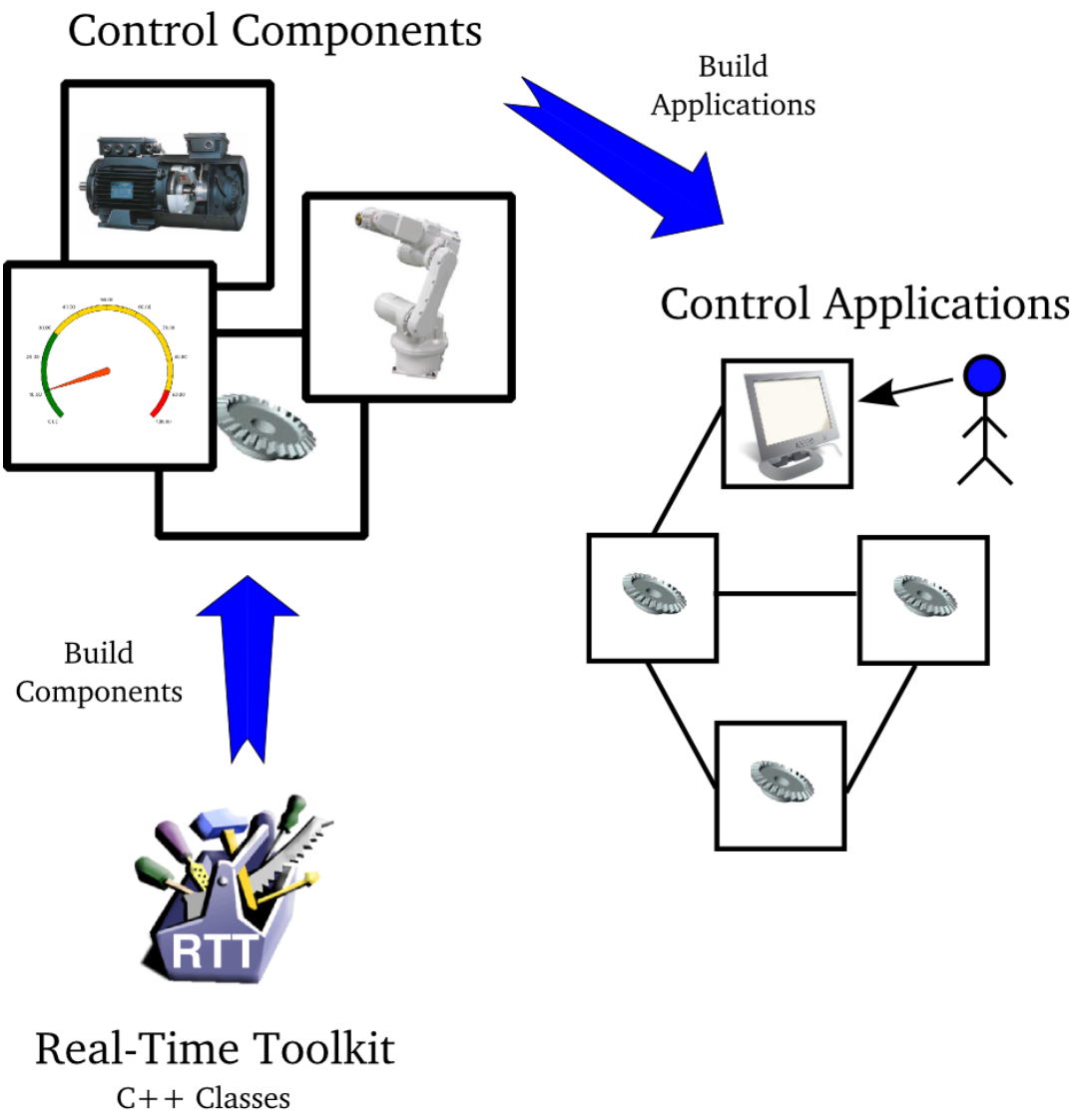


Figure 1.2. Orocos Real-Time Toolkit

3.1. Application Templates

An "Application Template" is a set of components that work well together. For example, the application template for motion control contains components for path planning, position control, hardware access and data reporting. The components are chosen as such that their interfaces are compatible.

An application template should be so simple that any Orocos user can pick one and modify it, hence it is the first thing a new user will encounter. An application template should be explainable on one page with one figure explaining the architecture.

Note

An application template has no relation to 'C++' templates.

3.2. Control Components

Applications are constructed using the Orocos "Control Component". A distributable entity which has a control oriented interface.

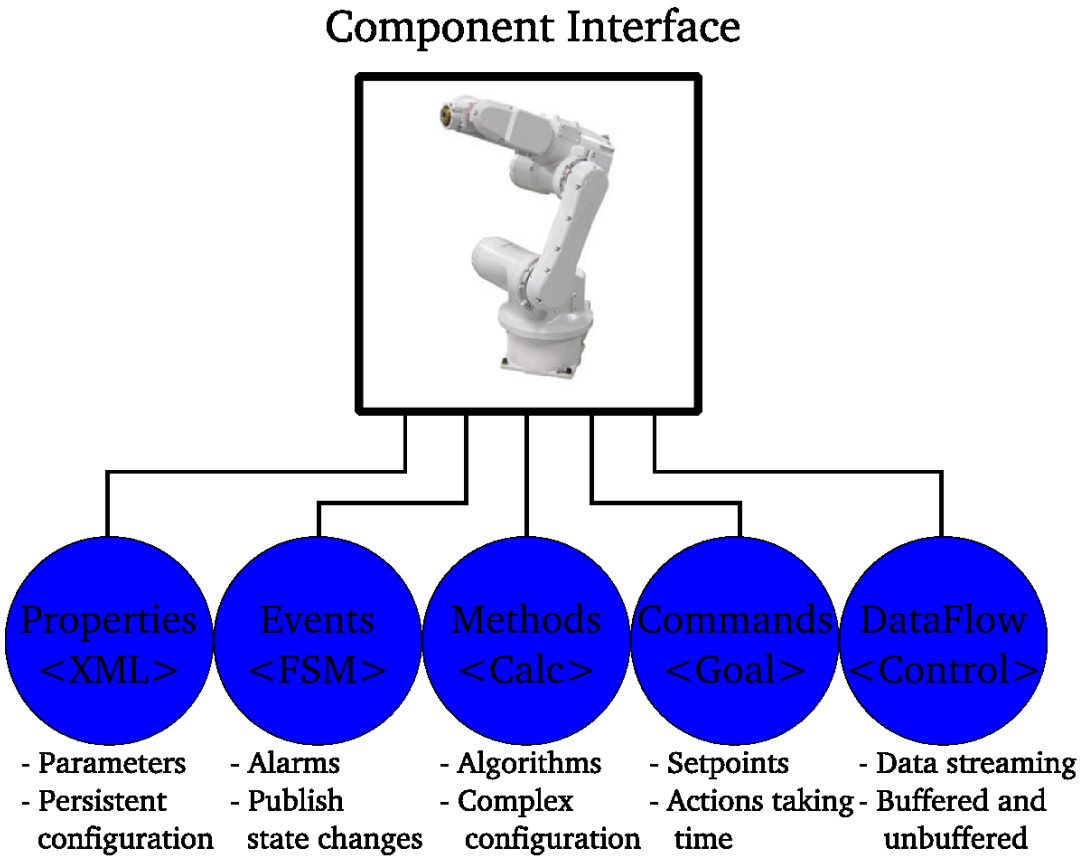


Figure 1.3. Orocos Control Component Interface

A single component may be well capable of controlling a whole machine, or is just a 'small' part in a whole network of components, for example an interpolator or kinematic component. The components are built with the "Real-Time Toolkit" and optionally make use of any other library (like a vision or kinematics toolkit). Most users will interface components through their (XML) properties or command/method interface in order to configure their applications.

There are five distinct ways in which an Orocos component can be interfaced: through its properties, events, methods, commands and data flow ports (Figure 1.3, “ Orocos Control Component Interface ”). These are all optional interfaces. The purpose and use of these interface 'types' is documented in the Orocos Component Builder's Manual. Each component documents its interface as well. To get a grip on what these interfaces mean, here are some fictitious component interfaces for a 'Robot' Component:

- *Data-Flow Ports:* Are a thread-safe data transport mechanism to communicate buffered or un-buffered data between components. For example: "JointSet-

points", "EndEffectorFrame", "FeedForward",...

- *Properties:* Are run-time modifiable parameters, stored in XML files. For example: "Kinematic Algorithm", "Control Parameters", "Homing Position", "ToolType",...
- *Methods:* Are callable by other components to 'calculate' a result immediately, just like a 'C' function. For example: "getTrackingError()", "openGripper()", "writeData("filename")", "isMoving()", ...
- *Commands:* Are 'sent' by other components to instruct the receiver to 'reach a goal' For example: "moveTo(pos, velocity)", "home()",... A command cannot, in general, be completely executed instantaneously, so the caller should not block and wait for its completion. But the Command object offers all functionalities to let the caller know about the progress in the execution of the command.
- *Events:* Allows functions to be executed when a change in the system occurs. For example: "Position Reached", "Emergency Stop", "Object Grasped",...

Besides defining the above component communication mechanisms, Orocos allows the Component or Application Builder to write hierarchical state machines which use these primitives. This is the Orocos way of defining your application specific logic. State machines can be (un-)loaded at run-time in any component.

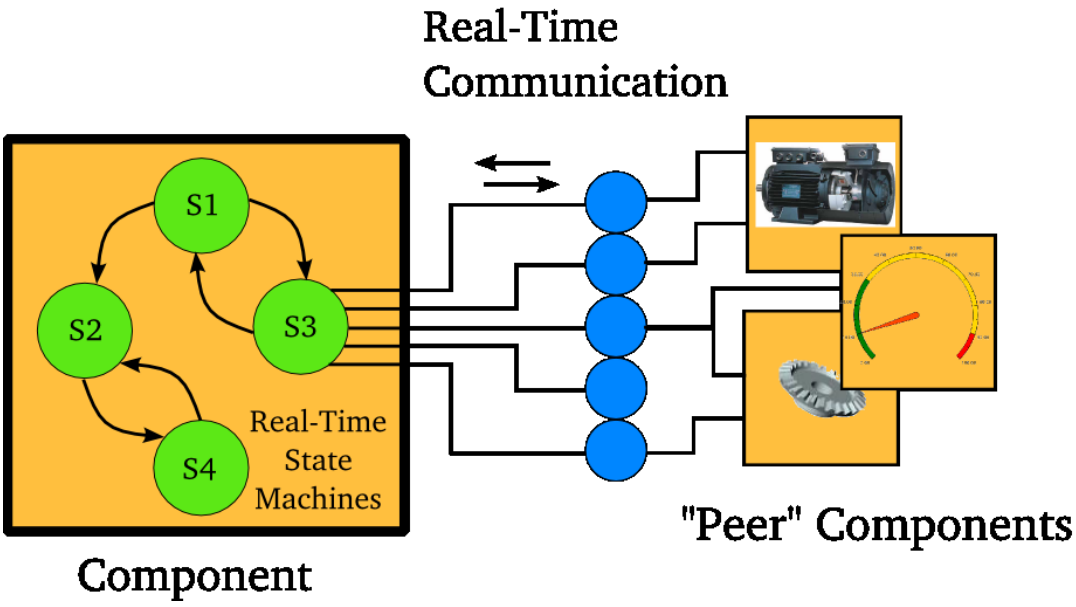


Figure 1.4. Orocos Control Component State Machines.

4. Related 'Orocos' Projects

The Orocos project spawned a couple of largely independent software projects. The documentation you are reading is about the Real-Time Control Software located on

the Orocos.org web page. The other *not real-time* projects are :

- At KTH Stockholm, several releases have been made for component-based robotic systems, and the project has been renamed to Orca [http://orca-robotics.sourceforge.net/].
- Although not a project funded partner, the FH Ulm maintains Free CORBA communication patterns for modular robotics : Orocos::SmartSoft [http://www.rz.fh-ulm.de/~cschlege/orocos/].

This documentation is targeted at industrial robotics and real-time control.

Chapter 2. Installing Orocos

This document explains how the Real-Time Toolkit of Orocos [http://www.orocos.org], the *Open RObot COntrol Software* project must be installed and configured.

1. Setting up your first Orocos source tree

1.1. Introduction

This sections explains the supported Orocos targets and the Orocos versioning scheme.

1.1.1. Supported platforms (targets)

Orocos was designed with portability in mind. Currently, we support RTAI/LXRT (http://www.rtai.org), GNU/Linux userspace, Xenomai (Xenomai.org [http://www.xenomai.org]). So, you can first write your software as a normal Linux program, using the framework for testing and debugging purposes in plain user-space Linux and recompile later to another real-time target.

1.1.2. The versioning scheme

Orocos uses the even/stable uneven/unstable version numbering scheme, just as the Linux kernel. A particular version is represented by three numbers separated by dots. An *even* middle number indicates a *stable* version. For example :

- 1.1.4 : Release 1, unstable (1), revision 4.
- 1.2.1 : Release 1, stable (2), revision 1.

This numbering allows to develop and release two kinds of versions, where the unstable version is mainly for testing new features and designs and the stable version is for users wanting to run a reliable system.

1.1.3. Dependencies on other Libraries

Before you install Orocos, verify that you have the following software installed on your platform :

Table 2.1. Build Requirements

Program / Library	***Minimum* Version**	**Description**
Boost C++ Libraries	0.32.0 (0.33.0 or newer	Boost.org [ht-

Program / Library	***Minimum* Version**	**Description**
	Recommended!)	tp://www.boost.org] Version 0.33.0 has a very efficient (time/space) lock-free smart pointer implementation which is used by Orocos.
GNU gcc / g++ Compilers	3.3.0	gcc.gnu.org [http://gcc.gnu.org] Orocos builds with the GCC 4.x series as well.
Xerces C++ Parser	2.1 (Optional)	Xerces website [http://xml.apache.org/xerces-c/] Versions 2.1 until 2.6 are known to work. If not found, an internal XML parser is used.
CppUnit Library	1.9.6 (Optional)	CppUnit website. [http://cppunit.sourceforge.net/cgi-bin/moin.cgi] Only needed if you want to run the Orocos tests.

All these packages are provided by most Linux distributions. Take also a look on the Orocos.org download page for the latest information.

1.2. Basic Real-Time Toolkit Installation

The RTT uses the CMake [http://www.cmake.org] build system for configuring and building the library.

1.2.1. Orocos Build and Configuration Tools

The tool you will need is **cmake** In Debian, you can use the official Debian version using

```
apt-get install cmake
```

If this does not work for you, you can download cmake from the CMake homepage.

1.2.2. Quick Installation Instructions

Download the orocos-rtt-1.2.2-src.tar.bz2 package from the Orocos webpage.

Extract it using :

```
tar -xvjf orocos-rtt-1.2.2-src.tar.bz2
```

Then proceed as in:

```
mkdir orocos-rtt-1.2.2/build
cd orocos-rtt-1.2.2/build
../configure --with-<target> [--prefix=/usr/local][--with-linux=/usr/src/linux]
make
make check
make install
```

Where

- <target> is one of listed in **../configure --help**. (currently 'gnulinux', 'lxrt' or 'xenomai'). When none is specified, 'gnulinux' is used.
- --prefix specifies where to install the RTT.
- --with-linux is required for RTAI/LXRT and older Xenomai version (<2.2.0). It points to the source location of the RTAI/Xenomai patched Linux kernel.

See **configure --help** for a full list of options.

Note

The **configure** script is a wrapper around the 'cmake' command and must be rerun after you installed missing libraries (like Boost, ...) before you can build the RTT.

1.2.3. Real-Time Toolkit Flavours

The RTT can be compiled in three flavours: the 'standard', 'embedded' or 'CORBA' version. The embedded version is standard without scripting, the CORBA version is standard with CORBA interfaces. In order to select your flavour, you need to invoke the **ccmake** command:

```
cd orocos-rtt-1.2.2/build
cmake ..
```

from your build directory. It will offer a configuration screen. The keys to use are 'arrows'/'enter' to modify a setting, 'c' to run a configuration check (may be required multiple times), 'g' to generate the makefiles. If an additional configuration check is required, the 'g' key can not be used and you must press again 'c' and examine the output.

RTT with CORBA flavour

In order to enable CORBA a valid installation of TAO must be detected on your system and you must turn the ENABLE_CORBA option on (using ccmake). Enabling CORBA almost doubles the size of the RTT library and slows down link and compile times.

Alternatively, when you use the configure wrapper, you can specify:

```
../configure --enable-corba
```

Embedded RTT flavour

In order to run Orocos applications on embedded systems, one can turn the OS_EMBEDDED option on. Next press 'c' again and additional options will be presented which allow you to select what part of the RTT is used. By default, the OS_EMBEDDED option already disables some 'fat' features. One can also choose to build the RTT as a static library (BUILD_STATIC).

Alternatively, when you use the configure wrapper, you can specify:

```
../configure --embedded
```

1.2.4. Build results

The **make** command will have created a liborocos-rtt.so library, and if CORBA is enabled a liborocos-rtt-corba.so library.

The **make docapi** and **make docpdf dochtml** (both in 'build') commands build API documentation and PDF/HTML documentation in the build/doc directory.

1.2.5. Building Orocos for multiple targets

When you want to build for another target, create a new build-<target> directory and simply re-invoke ../configure --with-<target> from that build directory.

If this step fails, it means that you have not everything installed which is needed for a basic Orocos build. Most users don't have the Boost library (libboost-dev or libboost-devel) installed. Install this package from the binary or source package repository of your Linux distribution, or download and install it from the Boost project. [http://www.boost.org] As soon as the configure step succeeds, all the rest will succeed too. Use the mailinglist at <orocos-dev@lists.mech.kuleuven.be> for support questions.

1.3. Installing an Orocos Build

Orocos can optionally (*but recommended*) be installed on your system with

```
make install
```

The default directory is /usr/local, but can be changed with the --with-prefix option :

```
../configure --with-prefix=/opt/other/
```

If you choose not to install Orocos, you can find the build's result in the build/rtt directory.

2. Detailed Configuration using 'CMake'

In order to start cmake configuration, in your build directory, run **ccmake ..** . Press 'c' (from 'c'onfigure), watch the output, press 'e' (from 'e'xit) and modify the new options. Repeat these steps until no errors are reported and the 'g' (from 'g'enerate) key can be pressed. This causes the makefiles to be generated which allow the library to be built.

2.1. Configuring the target Operating System

Move to the OROCOS_TARGET, press enter and type on of the following supported targets (all in lowercase):

- gnulinux
- xenomai
- lxrt

The xenomai and lxrt targets require the presence of the LINUX_SOURCE_DIR option since these targets require Linux headers during the Orocos build. To use the LibC Kernel headers in /usr/include/linux, specify /usr. Inspect the output to find any errors.

Note

From Xenomai version 2.2.0 on, Xenomai configuration does no longer require the --with-linux option.

2.2. Setting Build Compiler Flags

You can set the compiler flags using the CMAKE_BUILD_TYPE option. You may edit this field to contain:

- RTT (default)
- Release
- Debug
- RelWithDebInfo

2.3. Building for RTAI / LXRT

Read first the 'Getting Started' section from this page [http://people.mech.kuleuven.be/~psoetens/portingtolxrt.html] if you are not familiar with RTAI installation

Orocos has been tested with RTAI 3.0, 3.1, 3.2, 3.3, 3.4 and 3.5. You can obtain it from the RTAI home page [http://www.aero.polimi.it/projects/rtai/]. Read The README.* files in the rtai directory for detailed build instructions, as these depend on the RTAI version.

2.3.1. RTAI settings

RTAI comes with documentation for configuration and installation. During 'make menuconfig', make sure that you enable the following options (*in addition to options you feel you need for your application*) :

- General -> 'Enable extended configuration mode'
- Core System -> Native RTAI schedulers > Scheduler options -> 'Number of LXRT slots' ('1000')
- Machine -> 'Enable FPU support'
- Core System -> Native RTAI schedulers > IPC support -> Semaphores, Fifos, Bits (or Events) and Mailboxes
- Add-ons -> 'Comedi Support over LXRT' (if you intend to use the Orocos Comedi Drivers)
- Core System -> Native RTAI schedulers > 'LXRT scheduler (kernel and user-space tasks)'

After configuring you must run 'make' and 'make install' in your RTAI directory: **make sudo make install**

After installation, RTAI can be found in /usr/realtime. You'll have to specify this directory in the RTAI_INSTALL_DIR option during 'ccmake'.

2.3.2. Loading RTAI with LXRT

LXRT is a all-in-one scheduler that works for kernel and userspace. So if you use this, you can still run kernel programs but have the ability to run realtime programs in userspace. Orocos provides you the libraries to build these programs. Make sure that the following RTAI kernel modules are loaded

- rtai_sem
- rtai_lxrt

- rtai_hal
- adeos (depends on RTAI version)

For example, by executing as root: **modprobe rtai_lxrt; modprobe rtai_sem**.

2.3.3. Compiling Applications with LXRT

Application which use LXRT as a target need special flags when being compiled and linked. Especially :

- Compiling : -I/usr/realtime/include

  This is the RTAI headers installation directory.

- Linking : -L/usr/realtime/lib -llxrt for dynamic (.so) linking OR add /usr/realtime/liblxrt.a for static (.a) linking.

Important

You might also need to add /usr/realtime/lib to the /etc/ld.so.conf file and rerun **ldconfig**, such that liblxrt.so can be found. This option is not needed if you configured RTAI with LXRT-static-inlining.

2.4. Building for Xenomai (version 2.2.0 or newer)

Note

For older Xenomai versions, consult the Xenomai README of that version.

Xenomai provides a real-time scheduler for Linux applications. See the Xenomai home page [http://www.xenomai.org]. Xenomai requires a patch one needs to apply upon the Linux kernel, using the **scripts/prepare-kernel.sh** script. See the Xenomai installation manual. When applied, one needs to enable the General Setup -> Interrupt Pipeline option during Linux kernel configuration and next the Real-Time Sub-system -> , Xenomai and Nucleus. Enable the Native skin, Semaphores, Mutexes and Memory Heap. Finally enable the Posix skin as well.

When the Linux kernel is built, do in the Xenomai directory: **./configure ; make; make install**.

You'll have to specify the install directory in the XENOMAI_INSTALL_DIR option during 'ccmake'.

2.4.1. Loading Xenomai

The RTT uses the native Xenomai API to address the real-time scheduler. The Xenomai kernel modules can be found in /usr/xenomai/modules. Only the following kernel modules need to be loaded:

- xeno_hal.ko
- xeno_nucleus.ko
- xeno_native.ko

in that order. For example, by executing as root: **insmod xeno_hal.ko; insmod xeno_nucleus.ko; insmod xeno_native.ko**.

2.4.2. Compiling Applications with Xenomai

Application which use Xenomai as a target need special flags when being compiled and linked. Especially :

- Compiling : -I/usr/xenomai/include

  This is the Xenomai headers installation directory.

- Linking : -L/usr/xenomai/lib -lnative for dynamic (.so) linking OR add /usr/xenomai/libnative.a for static (.a) linking.

Important

You might also need to add /usr/xenomai/lib to the /etc/ld.so.conf file and rerun **ldconfig**, such that libnative.so can be found automatically.

2.5. Configuring for CORBA

In case your application benefits from remote access over a network, the RTT can be used with 'The Ace Orb' or *TAO* version prepared by OCI (Object Computing Inc.). You can find the latest TAO version on OCI's TAO website [http://www.theaceorb.com]. The RTT was tested with OCI's TAO 1.3 and 1.4. The OCI version is prefered above the versions provided by the DOC group on the Real-time CORBA with TAO (The ACE ORB) website [http://www.cs.wustl.edu/~schmidt/TAO.html].

Note

Orocos requires the ACE, TAO and TAO-orbsvcs libraries and header files to be installed on your workstation and *that the ACE_ROOT and TAO_ROOT variables are set.*

2.5.1. TAO installation (Optional)

Note

If your distribution does not provide the TAO libraries, or you want to use the OCI version, you need to build manually. These instructions are for building on Linux. See the ACE and TAO installation manuals for building on your platform.

You need to make an ACE/TAO build on your workstation. Download the package here: OCI Download [http://www.theaceorb.com/downloads/1.4a/index.html]. Unpack the tar-ball, and enter ACE_wrappers. Then do: **export ACE_ROOT=$(pwd) export TAO_ROOT=$(pwd)/TAO** Configure ACE for Linux by doing: **ln -s ace/config-linux.h ace/config.h ln -s include/makeinclude/platform_linux.GNU include/makeinclude/platform_macros.GNU** Finally, type: **make cd TAO make cd orbsvcs make** This finishes your TAO build.

2.5.2. Configuring the RTT for TAO

Orocos will first try to detect your location of ACE and TAO using the ACE_ROOT and TAO_ROOT variables. If these are set, you can enable CORBA support (ENABLE_CORBA) within CMake.

Alternatively, when you use the configure wrapper, you can specify:

```
../configure --enable-corba
```

2.5.3. Application Development with TAO

Once you compile and link your application with Orocos and with the CORBA functionality enabled, you must provide the correct include and link flags in your own Makefile if TAO and ACE are not installed in the default path. Then you must add:

- Compiling : -I/path/to/ACE_wrappers -I/path/to/ACE_wrappers/TAO

  This is the ACE build directory in case you use OCI's TAO packages. This option is not needed if you used your distribution's TAO installation, in that case, TAO is in the standard include path.

- Linking : -L/path/to/ACE_wrappers/lib -lTAO -lACE -lTAO_IDL_BE -lTAO_PortableServer -lTAO_CosNaming

  This is again the ACE build directory in case you use OCI's TAO packages. The *first* option is not needed if you used your distribution's TAO installation, in that case, TAO is in the standard library path.

Important

You also need to add /path/to/ACE_wrappers/lib to the /etc/ld.so.conf file and rerun **ldconfig**, such that these libraries can be found. Or you can before you start your application type

```
export LD_LIBRARY_PATH=/path/to/ACE_wrappers/lib
```

.

3. Getting Started with the Code

This Section provides a short overview of how to proceed next using the Orocos Real-Time Toolkit.

3.1. A quick test

You can issue a **make check** in the Orocos build directory, but this stresses your system heavily. make check for the gnulinux target should successfuly complete.

To quickly test an Orocos application, you can download the examples from the webpage.

3.2. What about main() ?

The first question asked by many users is : How do I write a test program to see how it works?

Some care must be taken in initialising the realtime environment. First of all, you need to provide a function int ORO_main(int argc, char** argv) {...}, defined in <rtt/os/main.h> which contains your program :

```
#include <rtt/os/main.h>

int ORO_main(int argc, char** argv)
{
  // Your code, do not use 'exit()', use 'return' to
  // allow Orocos to cleanup system resources.
}
```

If you link with the liborocos-rtt.so library, this function will be called after the run-time environment is set up. To put in other words, the Orocos library already contains a main() function which will call the user-defined ORO_main() function.

Example 2.1. A Makefile for an Orocos Application

You can then simply compile your program with a Makefile resembling this one :

```
 OROPATH=/usr/local
 CXXFLAGS=`PKG_CONFIG_PATH=${OROPATH}/lib/pkgconfig pkg-config
orocos-rtt --cflags`
 LDFLAGS=`PKG_CONFIG_PATH=${OROPATH}/lib/pkgconfig pkg-config orocos-rtt
--libs`

 all: myprogram.cpp
      g++ myprogram.cpp ${CXXFLAGS} ${LDFLAGS} -o myprogram
```

The flags must be extended with compile and link options for your particular application.

Important

The LDFLAGS option must be placed after the .cpp or .o files in the gcc command.

Note

Make sure you have read Section 2, “Detailed Configuration using 'CMake'” for your target if you application has compilation or link errors (for example when using LXRT).

3.3. Header Files Overview

Table 2.2. Header Files

Header	Summary
rtt/*.hpp	The `Real-Time Toolkit' directory contains the headers which describe the public API.
rtt/os/*.h, rtt/os/*.hpp	Not intended for normal users. The os headers describe a limited set of OS primitives, like locking a mutex or creating a thread. Read the OS manual carefully before using these headers, they are mostly used internally by the RTT.
rtt/dev/*.hpp	C++ Headers for accessing hardware interfaces.
rtt/corba/*.hpp	C++ Headers for CORBA support.
rtt/scripting/*.hpp	C++ Headers for real-time scripting. Do not include these directly as they are mainly for internal use.

Header	Summary
rtt/marsh/*.hpp	C++ Headers for XML configuration and converting data to text and vice versa.
rtt/dlib/*.hpp	C++ Headers for the experimental Distribution Library which allows embedded systems to use some RTT primitives over a network. This directory does not contain such a library but only interface headers.
rtt/impl/*.hpp	C++ Headers for internal use.

4. Cross Compiling Orocos

This section lists some points of attention when cross-compiling Orocos.

Run plain "cmake" or "ccmake" with the following options:

```
CC=cross-gcc CXX=cross-g++ cmake .. -DCROSS_COMPILE=cross-
```

and substitute the 'cross-' prefix with your target tripplet, for example with 'power-pc-linux-gnu-'.